CdS and PbS thin films were deposited using a wet chemistry deposition technique [4]. Cadmium nitrate and cadmium acetate are used as the source of Cd ions; lead nitrate the source of Pb ions; and thiourea, $(SC(NH_2)_2)$, the source of S ions. It is important to accurately control pH of these solutions since the CdS and PbS precipitates are stable only in the pH range 10 to 13. pH control and chelating is achieved using an ammonia solution for CdS and sodium hydroxide for PbS. Specifically, the pH for aqueous $Cd(NO_3)_2$ is maintained between 11 and 12. Since the reaction rate also changes with the pH, it is necessary to calibrate the process for a given pH range. The thickness of both CdS and PbS increases with increasing concentration of Cd, Pb and S ions in solution and with increasing deposition time. From a study of the growth kinetics for both CdS and PbS thin films, we have established optimal concentration and flow rate conditions for uniform film deposition for tubing with lengths greater than 1.5 m. The best coatings were made using > 0.01 M solutions and pumping rates of 30 ml/min.

The multilayer dielectric structures of Ag/CdS/PbS and Ag/CdS/PbS/CdS, were prepared in a manner similar to the single-layer dielectric metallic waveguides. The different layers were coated in a sequential manner with an intermediate drying step after coating each layer. An Ag-only tube was coated with a single layer of either CdS or PbS when the 2- and 3-layer structures were being coated as an independent check on the thickness for each layer.

3. Optical characterization of Ag/sulfide film HGWs

The spectral characteristics of the Ag/CdS and Ag/PbS HGWs were evaluated using a Perkin Elmer UV-VIS spectrometer and Nicolet Protégé FTIR. A typical spectral response shows interference peaks which depend on the thickness of the dielectric thin films. The thickness of a single layer dielectric, d, was calculated from the peak position of the longest-wavelength interference band, $\lambda_p^{(m)}$, using the relation [12],

$$d = \frac{m \cdot \lambda_p^{(m)}}{4 \cdot \sqrt{n_1^2 - 1}}, \tag{1}$$

where m is the order of the interference maxima ($m = 1$ for the longest-wavelength band); λ_p is the wavelength of the m^{th} absorption peak; and n_1 is the refractive index of the dielectric film. From Eq. (1) we see that the peak position shifts to longer wavelengths as the thickness of the film increases. Spectral data has been used to determine the thickness of films prepared using different growth kinetics. The film thickness obtained from the optical measurements has then been correlated with direct thickness measurements using a field-emission scanning electron microscope (FESEM). In this way we obtain the growth kinetic curves for CdS and PbS deposited on Ag, shown in Fig. 1.

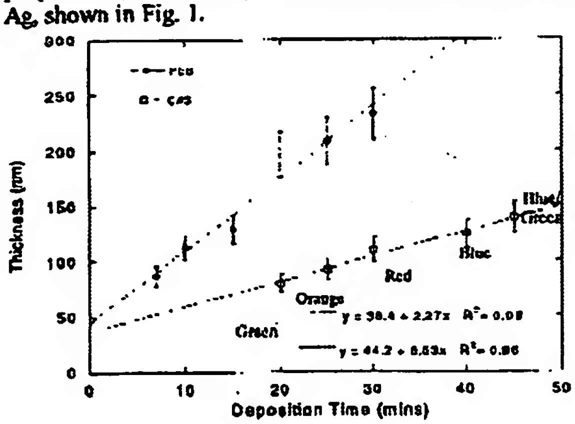

Fig. 1 The growth kinetic curves of the CdS and PbS thin films deposited in a Ag coated, 1,000 µm bore HGWs. The color indicated is the color that one would see looking through the waveguides with an optical microscope.

The thickness of the thin films was obtained by direct measurements using a FESEM. A photomicrograph taken with the FESEM for a typical cross-section of the thin film combination Ag/CdS/PbS is shown in Fig. 4. The CdS film appears darker than the PbS film because the in-lens detector produces a negative image of the secondary electron image. The thicknesses of the films shown in Fig. 4 are; Ag 154 nm, CdS 169 ± 16 nm, PbS 82 ± 6 nm. We do not see any degradation of the underlying film when the new film is deposited over it. That is, CdS and PbS do not react with each other during the deposition of successive layers. The film thickness measured from the FESEM micrographs of both single and multilayer dielectric film are summarized in Table 1. These results agree very well with the optical thickness measurement.

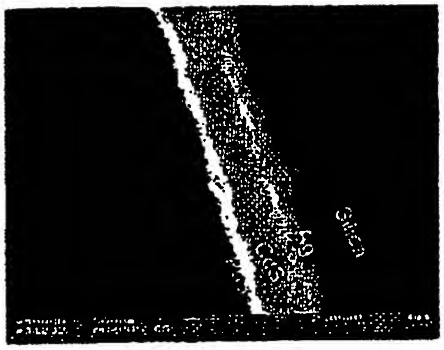

Fig. 4 Cross sectional FESEM image of a 1,000-μm bore Ag/CdS /PbS HGW. The CdS and PbS thin films are deposited sequentially inside the Ag coated HGW.

Table 1 Thickness values for CdS and PbS thin films on Ag determined from FESEM images

HGWs	Thickness of Ag nm	Thickness of CdS nm	Thickness of PbS nm
Ag/CdS	156 ± 16	172 ± 16	—
Ag/PbS	158 ± 20	—	96 ± 16
Ag/CdS/PbS	154	169	82 ± 6

A series of 1,000-μm-bore HGWs with 1, 2, and 3 dielectric layers deposited over Ag were fabricated using wet chemistry methods [8, 11]. The spectral losses for these straight waveguides are shown in Fig. 5. From Fig. 5, it may be seen that the addition of each dielectric layer shifts the interference peaks to longer wavelengths. This is a result of the increase in thickness with each additional layer.

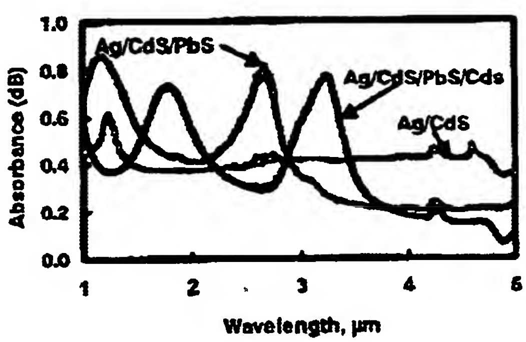

Fig. 5 FTIR Spectra of a 1,000-μm bore of 1, 2, and 3-layer dielectric coatings on Ag coated HGWs. The spectra beyond 4 to 12 μm region are essentially flat and featureless.

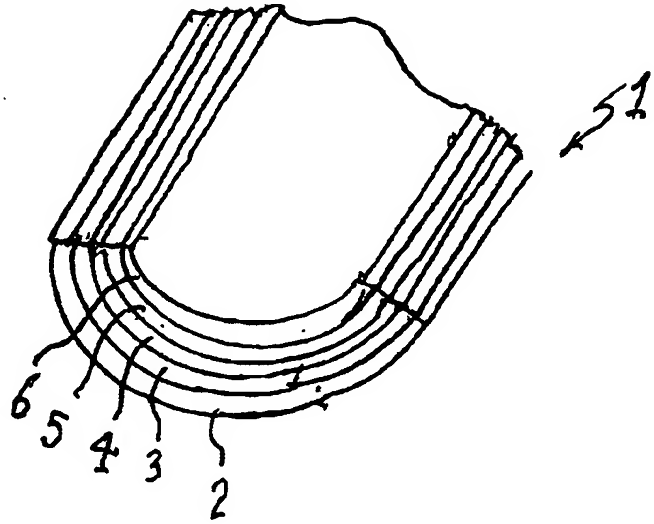

FIGURE 6

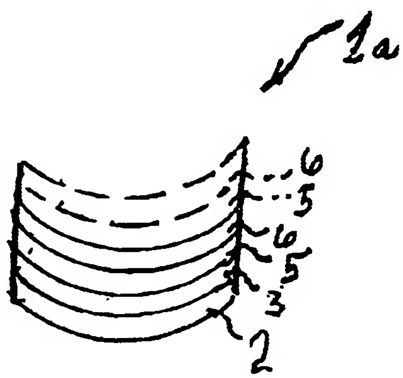

FIGURE 6a

All films were prepared using 0.01 M solutions and a flow rate of 30 ml/min. The growth kinetics curves in Fig. 1 indicate that CdS (open symbols) has a slower growth rate on Ag compared to PbS (solid symbols) under similar conditions. The reason for the slower growth rate for CdS compared to PbS is that the CdS complexes with the ammonia used in the deposition and this decreases the rate of deposition. The data also show that the thickness of both dielectrics increases linearly with time, with growth rates of ~ 2.3 and 6.9 nm/min for CdS and PbS, respectively. The mechanism for linear growth is based on the Stransi-Krastanov model of island-like growth [16]. This mechanism involves nucleation and growth and we are in the linear growth region. This information is important as we need to carefully control film thickness for single and multilayer structures. The UV-VIS spectra for the Ag/CdS is given in Fig. 2 and the FTIR spectra for the Ag/PbS in Fig. 3. The spectral data clearly show that the position of the interference peaks shifts to longer wavelengths as the thickness of the film increases as predicted by Eq. (1). We also note from the insert photos in Fig. 2 that the HGWs show a color variation. This is due to selective filtering of the input white light by the thin film coating (interference effect). This color variation is seen with the CdS coatings but not the PbS films as these films do not transmit well at visible wavelengths.

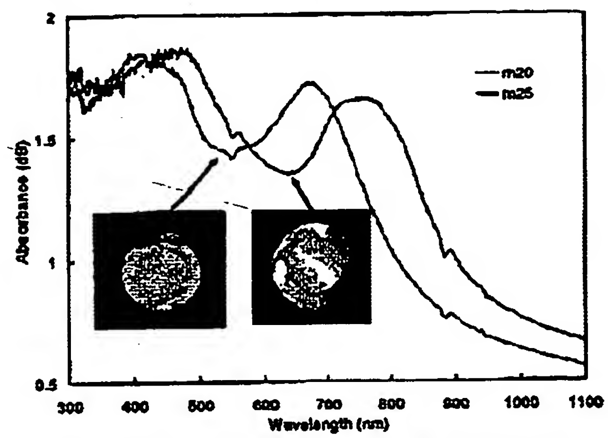

Fig. 2 UV-VIS spectra of 1,000-μm bore Ag/CdS HGWs for different deposition times in m minutes. The insert shows the color of the transmitted light as filtered by the coating.

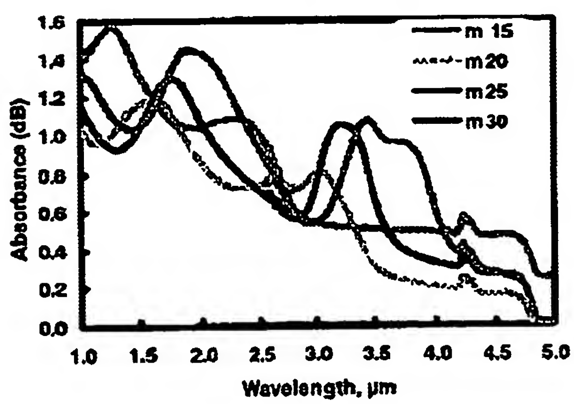

Fig. 3 FTIR spectra of 1,000-μm bore Ag/PbS HGWs for different deposition times in m minutes.